Acoustic Analysis of Internally versus Externally Guided Speech in Parkinson's Disease

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Abstract

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It is well established that individuals with Parkinson's disease (PD) exhibit differences in their ability to perform internally guided (IG) movements versus externally guided (EG) movements. The goal of this study was to evaluate the vocal parameters of utterances produced by ten speakers with Parkinson's disease in two contexts: covert conversation (an IG context) and sentence reading (an EG context). Analyses were centered on measures of dysfluency, speaking rate and pitch variation. Results revealed significant differences for two of the ten speakers between speaking conditions. Namely, these speakers spoke faster and more fluently in the EG condition. Findings partially align with those of the original study (Weir-Mayta, 2014), which found perceptually salient differences between IG and EG conditions for six of the ten speakers. Future research is needed to continue to explicate the effects of external cuing on motor speech performance in individuals with PD.

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Introduction

It is well established that individuals with Parkinson's disease (PD) exhibit significant differences in their ability to perform internally guided (IG) movements versus externally guided (EG) movements (Lewis, et al., 2007). An IG movement requires volitional initiation, whereas an EG movement is triggered by some sensory event such as external visual or auditory cues (Lewis et al., 2007). It is hypothesized that the dopaminergic deficits, which characterize PD and adversely affect basal ganglia function, impact the basal ganglia's ability to communicate with fronto-striatal networks. Both the basal ganglia and fronto-striatal networks are strongly implicated in the planning and execution of IG movements (Lewis, 2007). Thus, dopaminergic depletion is thought to result in the inability of individuals with PD to effectively execute IG movements and have a concomitant overreliance on external cues to perform skilled movements (Lewis, 2007; Weir-Mayta, 2014). While there is ample evidence to support the presence of these differences in execution of IG versus EG skilled limb movements such as gait (Luessi, Mueller, Breimhorst, & Vogt, 2012), writing (Oliveira, Gurd, Nixon, Marshall, & Passingham, 1997), and driving (Stolwyk, Triggs, Charlton, Iansek, & Bradshaw, 2005), evidence that supports differences in performance on IG speech production (e.g., conversation) versus EG speech production (e.g., reading aloud) has been inconsistent (Weir-Mayta, 2014).

Perceptual analysis by experienced listeners in Weir-Mayta (2014) revealed significant improvements in prosodic performance and articulatory precision in an EG speaking task (i.e., sentence reading task) compared to an IG speaking task (i.e., conversation). The purpose of the present study is to acoustically examine the recorded speech samples of this study's participants in both the IG and EG speaking tasks to better understand how participants modified their speech depending on speaking task. Specifically, we will examine speaking rate, fundamental frequency (F0) variability and range, and fluency of speech in relation to improvements in prosodic performance and articulatory precision.

To establish the foundation and need for the proposed study, an overview of hypokinetic dysarthria will be provided along with a review of the anatomical and physiological correlates of impaired IG movements in individuals with PD. Following this, findings from available studies on the performance of speakers with PD in IG versus EG speaking tasks and the outcome measures used to capture said performance will be discussed. Lastly, the clinical implications of such findings will be used to build the rationale for the present study.

Hypokinetic dysarthria

Parkinson's Disease (PD) is an idiopathic neurodegenerative disorder that affects 1-2% of the population over the age of 50 (Duffy, 2013). PD is characterized by a slow and progressive loss of dopaminergic neurons in the substantia nigra, locus ceruleus as well as decreased dopamine in the striatum (Duffy, 2013). This cell loss manifests in the cardinal motor features of the disease: tremor at rest, rigidity, bradykinesia and loss of postural reflexes.

In addition to these features, dysarthria is a common complication of PD and emerges in 90% of cases over the course of the disease (Duffy, 2013). The dysarthria type most commonly associated with PD is *hypokinetic dysarthria*, a motor speech disorder caused by dysfunction of the basal ganglia control circuit that can either result from the effects of PD itself and/or the medications used to treat it. Hypokinetic dysarthria may manifest in any of the subsystems of speech: respiratory, phonatory, resonatory, or articulatory; however, its effects are most commonly observed in the areas of voice, articulation and prosody (Duffy, 2013). The most deviant speech characteristics of hypokinetic dysarthria listed in order from most to least severe are: monopitch, reduced stress, monoloudness, imprecise consonants, inappropriate silences, short rushes of speech, harsh voice quality, breathy voice, low pitch and variable rate (Darley, Aronson & Brown, 1969 as cited in Duffy, 2013).

Anatomical and physiological correlates of internally-guided movements

As previously stated, studies from the motor control literature suggest that IG limb movements are more impaired than EG movements in individuals with PD (Oliveira et al., 1997; Stolwyk, Cameron, Bonura & Sidtis, 2012). There is also evidence to suggest that this pattern of performance may apply to motor speech production, and that the aforementioned characteristics of hypokinetic dysarthria are not consistent across types and contexts of speech production in dysarthric individuals with PD (Kempler & Van Lancker, 2002; Sidtis et al., 2012). For example, individuals with PD have been shown to perform better on EG speaking tasks such as reading aloud. The hypothesized reason for these differences in IG versus EG movements lies in the pathology associated with PD, specifically, in the dopaminergic deficits that compromise function of the basal ganglia (Graybiel, 2000).

The basal ganglia consist of several nuclei, namely: the striatum, composed of the caudate nucleus and the putamen, and the lentiform nucleus, composed of the putamen and globus pallidus. The substantia nigra and subthalamic nuclei are located closely to and are heavily involved in basal ganglia function (Duffy, 2013). Taken together, the primary functions of the basal ganglia are to: regulate muscle tone, control postural adjustments during skilled movements, regulate movements that support goal-directed activities, scale the force, amplitude and duration of movements, adjust movements to the environment and assist in the learning, preparation and initiation of movements (Duffy, 2013). The nuclei receive afferent fibers from the cerebral cortex via the striatum. The major output pathways of the basal ganglia exit through the globus pallidus and travel through the thalamus for relay to the frontal cortex (Duffy, 2013). Pertinent to the execution of IG movements are the efferent fibers the basal ganglia project to the supplementary motor area (SMA). The SMA also sends fibers to the basal ganglia (Saint-Cyr et al., 1995) that transmit information critical to the initiation of movement and inhibition of unwanted movement, and involve the SMA in the execution of IG movements (Weir-Mayta, 2014).

Findings from Cunnington, Iansek, Bradshaw, and Phillips (1995) reveal SMA interaction with the basal ganglia to mediate the execution of IG *and* EG guided movements, with specific involvement in the temporal organization of voluntary and IG sequential movements in healthy individuals. However, for individuals with

PD, the SMA was active in execution of IG movements *only*. Furthermore, this activity was significantly different from that of healthy controls with delayed onset, peak SMA activity, and prolonged SMA activation following execution of IG movement in individuals with PD (Cunnington et al., 1995). Given these findings, the authors concluded that the IG motor control mechanism in individuals with PD is impaired due to disrupted input from the basal ganglia; thus, an over-reliance on external cues is necessary to bypass the impaired IG motor control mechanism and execute desired movements. Such a model serves to explicate the mechanism underlying the enhanced performance of individuals with PD when executing EG movements as opposed to IG movements.

Internally versus externally guided speaking tasks

Studies have investigated the differences between IG versus EG connected speech of individuals with PD using varying speech elicitation conditions. Variability of speech performance was examined by Kempler and Van Lancker (2002) who measured speech intelligibility across five tasks, which included speaking and reading. The study's participant was a 74 yr. old male with PD and moderate hypokinetic dysarthria. The speaker was recorded during production of a spontaneous monologue with the examiner while another examiner transcribed 30 utterances extracted from the monologue. The participant was later instructed to read, repeat and sing these utterances. Sixty-four listeners that were provided a cloze format with 100 blanks for target words reviewed the recorded samples. Listeners were instructed to review samples in a sound field at a comfortable loudness level. Results revealed a statistically significant difference between poor (29%) intelligibility of spontaneous speech compared with better (78-88%) intelligibility in reading (Kempler & Van Lancker, 2002).

Further analysis exploring the relationship between intelligibility and acoustic characteristics of the stimuli revealed that loudness and mean word duration did not account for differences in intelligibility across conditions. A significantly greater number of dysfluencies (68%) were identified in spontaneous speech than in all other speech tasks. Additionally, spectrograms of recorded samples were rated using a scale of 1-4, i.e., 1="formants and consonant transitions shown with coherence and clarity" and 4="formants incoherent or smeared, and consonant transitions notably lengthened, scattered and otherwise not well-formed" (Kempler & Van Lancker, 2002, pp. 456). Eighty percent of spectrograms representing spontaneous speech utterances received a rating of four, whereas 36% of spectrograms depicting read utterances received a rating of one (Kempler & Van Lancker, 2002). The aforementioned findings align with those of the limb motor control literature to support increased performance on EG tasks versus IG tasks for individuals with PD. The authors suggested that the EG tasks (e.g., reading) provided enough external support to reduce the demands placed on the basal ganglia and other structures implicated in the execution of movements to plan, initiate and execute speech gestures; yet they acknowledged that the ways in which external supports accomplish this are yet poorly understood (Kempler & Van Lancker, 2002).

Sidtis and colleagues (2012) also examined variability in performance on IG versus EG speaking tasks. Participants consisted of 11 individuals with PD, 5 with PD *and* Deep Brain Stimulation, and all with mild hypokinetic dysarthria. Speech production was examined under two speaking conditions: monologue and repetition. Examiners recorded speech production during a spontaneous monologue and then extracted utterances, which participants were then instructed to repeat. Thirty listeners that were provided a cloze format for 176 utterances with 426 blanks for target words reviewed the recorded samples. They could adjust headphone volume to a comfortable level, and were asked to listen to each utterance once and write the word they heard in the blank provided. Following review of an utterance, listeners were then required to rate their difficulty in understanding the PD speaker using a five point rating scale. Results revealed a trend toward repetition being more intelligible than monologue for all participant groups (i.e., PD, PD/DBS ON and PD/DBS OFF), but was not significantly different from monologue (Sidtis et al., 2012). The authors stated these outcomes could possibly be due to the participants' mild level of hypokinetic dysarthria. With regard to difficulty ratings, listeners rated intelligibility as more difficult for monologue than for repetition for PD, DBS ON and DBS OFF (Sidtis et al., 2012). Further, acoustic analysis revealed higher harmonic-to-noise ratios (i.e., better voice quality) in repetition than monologue and fewer dysfluencies overall for repeated speech. Taken together, these findings also concur with those in the motor limb literature for increased performance on EG movements versus IG movements. The authors attributed the results of the study to reduced burden of effort for the basal ganglia in EG tasks (i.e., repetition) versus IG tasks (i.e., monologue) based on theories of motor behavior (Sidtis et al., 2012).

Findings from the previous two studies contrast with those of Tjaden & Wilding (2011) whose results suggest questionable benefit from provision of external supports in monologue and reading tasks. Of their twelve participants, ten had hypokinetic dysarthria, one hyperkinetic dysarthria and one hypo-hyperkinetic dysarthria. Severity of dysarthria ranged from mild to severe across participants. Participants performed two tasks: reading a passage aloud and producing a spontaneous two-minute monologue. Sixty listeners judged intelligibility of the reading passage using orthographic transcription and modulus-free Direct Magnitude Estimation (DME). For orthographic transcription of the reading passage, the listeners were required to write down what they perceived the speaker to say in the recorded sample. Percent correct scores were obtained for each listener; this was done by tallying the total number of correctly transcribed words, dividing by the total number of possible words and multiplying by 100. For DME, listeners were required to generate a scaled estimate of a given participant's "intelligibility," which was operationally defined as "the ease with which speech is understood" (Tjaden & Wilding, 2011, pp. 159). Scaled estimates were converted to a common scale and then averaged for overall mean intelligibility of each speech run and each participant. Speech run was operationally defined as, "a stretch of speech bounded by a silent period or pause between words ≥ 200ms" (Tjaden & Wilding, 2011, pp. 158). Results revealed average percent correct scores for orthographic transcription ranging from 66% for the least intelligible speaker to 97% for the most intelligible speaker. Statistical analysis of scaled scores generated by DME indicated no significant difference in scaled intelligibility for the paragraph reading and monologue tasks. This finding differs from those revealed in Kempler and Van Lancker (2002) and Sidtis et al. (2012) in that no observable benefit was derived from the provision of external cuing. However, methodological issues with this study raise concerns regarding the validity of its findings. First, the authors cited anecdotal evidence from a previous study they authored conveying that listeners find the DME task of numerically scaling intelligibility, in the absence of an anchor or modulus, to be unusual (Tjaden & Wilding, 2011). This is likely why measures to ascertain reliability for DME among listeners were not overwhelmingly strong in this study (Reading Passage: mean=0.33 and Monologue: mean=.42). Furthermore, a correlational analysis of scaled estimates of intelligibility for paragraph reading and monologue tasks revealed that these intelligibility measures were not strongly correlated. This means that a given speaker's intelligibility ranking for the reading passage cannot be considered representative of their intelligibility ranking for spontaneous speech. In other words, intelligibility between speaking tasks did differ even if differences between DME across speaking tasks were not statistically significant.

In summary, findings from available studies exploring differences between IG versus EG speaking tasks have inconsistently aligned with those of the motor limb literature, yet they all offer valid evidence to support the presence of differences in performance between IG and EG speaking tasks in individuals with PD. This is not to diminish the fact that one must use caution when reviewing research findings and not automatically assume that identical patterns of performance will be observed in all PD individuals. However, the presence of these differences does warrant further exploration into the particularities of the performance of individuals with PD on IG versus EG movements and/or speaking tasks to better understand why these differences occur.

The exact neural circuitry underlying these differences is not yet clearly understood, though a general model has emerged among studies. Several authors postulate that basal ganglia dysfunction results in the absence of the internal cues necessary to guide volitional movements, e.g., conversational speech. Therefore, provision of an external model, e.g., reading and repetition, bypasses the need for these internal cues and provides aid to the basal ganglia with which to plan, initiate and monitor the speech gesture (Cunnington et al., 1995; Kempler & Van Lancker, 2002; Sidtis et al., 2012).

In addition to this model, the question has risen of whether or not external cues heighten an individual's awareness and attention to task, thereby resulting in increased speaking performance and higher intelligibility of speech. In other words, is increased attention to task via provision of external and/or subtle environmental cues (e.g., presence of recording equipment) a causal factor in increased performance on EG speaking tasks? To address this question, Bunton & Keintz (2008) examined intelligibility in single and dual task paradigms in 4 individuals with PD and hypokinetic dysarthria (Hoehn & Yahr stage 3) and 4 age-matched controls. Speech samples were recorded during four different speaking tasks: monosyllabic word reading, low predictability sentence reading, production of a spontaneous monologue, and production of a covert monologue. With the exception of the covert monologue, speaking tasks were performed under two task paradigms: single task paradigm (i.e., speaking only) and dual-task paradigm (i.e., speaking while performing simultaneous motor task of turning a nut on a bolt). 96 listeners reviewed recorded samples at a consistent volume and were required to write down what they heard. Intelligibility measures were calculated by dividing the total number words correctly identified by the total number of possible words for a given speech task. Percentages were then averaged across listeners.

Results for the single-task paradigm revealed similar intelligibility scores for monosyllabic word reading (90.75%), low predictability sentence reading (90.2%) and spontaneous monologue (87.5%) in participants with PD. These findings concur with those of Tjaden & Wilding (2011) and do not align with findings from Kempler and Van Lancker (2002), Sidtis et al. (2012) or the motor limb literature that support improved performance in EG movements as compared to IG movements. Additionally, intelligibility scores for spontaneous monologue (87.5%) and covert monologue (74.25%) were not statistically different for participants with PD. Results for the dual-task paradigm revealed no significant differences among participants with PD or healthy controls across speaking tasks. Comparison of speech intelligibility scores in the single-task condition to those measured in the dual-task condition revealed significantly higher speech intelligibility scores for all speaking tasks in the single-task condition for PD participants *only*. These higher intelligibility scores were supported by changes in the acoustic characteristics of PD participants' speech, namely slower speech rate and greater F0 variation in speech produced for the single-task paradigm (Bunton & Keintz, 2008). Taken together, these findings implicate attention as a possible causal factor in increased performance on both IG speaking tasks (i.e., monologue) *and* EG speaking tasks (i.e., reading), and reveal negligible benefit of external cues for speech production in PD individuals. The authors attributed increased speech performance in the single-task paradigm to enhanced allocation of attentional resources. Simply stated, they hypothesize that an individual with PD will produce more intelligible speech in a structured setting (e.g., clinical setting) where they have explicit knowledge of the speaking task's goal (e.g., as provided by a speech-language pathologist), thereby increasing focus on speech production and optimizing performance. Conversely, an individual with PD will produce less intelligible speech when their attentional capacity is reduced due to lack of structure and expectation and/or a simultaneous task requiring more attentional resources.

Findings from Bunton and Keintz (2008) diverge from those of Weir-Mayta (2014) that indicate benefit to speaking ability from external cues, and do not support the notion of increased attention to task as the main mechanism underlying increased performance in an EG speaking task. In this study, the investigator had experienced listeners rate the *understandability* and *naturalness* of 16 participants under two speaking conditions: covert conversation and sentence reading. Sixteen participants completed the study, 10 with PD and 6 with cerebellar disease (CD). The PD group consisted of 9 males and one female, all with hypokinetic dysarthria ranging in severity from mild to severe. The examiner obtained three-minute recordings of covert conversation and then extracted the first eight utterances that met pre-specified selection criteria. Participants were then instructed to read these utterances using their typical speech.

Recordings for both tasks underwent perceptual analysis performed by ten speech-language pathologists with a minimum of five years of clinical experience who rated the qualities of *understandability* and *naturalness* using a 100-point visual analogue scale. *Understandability* was operationally defined as, "the speaker's articulatory precision" with the two ends of the scale labeled as “completely understandable” and “completely unable to understand”. *Naturalness* was operationally defined as, "“the speaker’s prosody – defined as speech rate, rhythm, intonation, stress patterns and loudness” with the two ends of the scale labeled as “completely natural” and “highly unnatural" (Weir-Mayta, 2014, pp. 39). Listeners were instructed to assign ratings after reviewing each audio recording once in a quiet room.

Results revealed that PD speakers were perceived as both significantly more *understandable* and *natural* in sentence reading than in covert conversation. Specifically, seven of the ten PD participants had more than a five-point increase in *understandability* and eight of the ten PD participants had more than a five-point increase in *naturalness* during sentence reading. Similar to the group with PD, speakers with CD were perceived as significantly more *understandable* during sentence reading, with two participants receiving more than a five-point increase in *understandability* ratings. However, with regard to *naturalness*, experienced listeners perceived participants with CD as equally natural in both reading and covert conversation. Inter-rater reliability calculations for all perceptual measures obtained a high level of agreement among listeners for both *understandability* (.867) and *naturalness* (.874), further reinforcing the validity of these findings. Whereas, these results also support previous studies' findings that suggest individuals with PD perform better on EG speaking tasks (e.g., reading) (Kemper & Van Lancker, 2002; Sidtis et al., 2011), they do not lend support to those of Bunton and Keintz (2008). If attention were the main underlying mechanism responsible for the increased performance observed during the EG speaking task (i.e., sentence reading), an increase in both *understandability* and *naturalness* should have been evident for speakers with PD *and* CD (Weir-Mayta, 2014). Thus, whereas it appears that increased attention does positively affect performance on IG and EG speaking tasks, it is perhaps not the main mechanism responsible for the differences in performance between IG and EG speaking tasks for individuals with PD. The author echoed the hypothesized mechanism underlying increases in speaking performance for EG speech gestures offered in previous studies (Kempler & Van Lancker, 2002; Sidtis et al., 2012). Namely, that basal ganglia dysfunction results in a lack of the internal cues necessary to guide volitional movements, and that provision of an external model provides aid to the basal ganglia with which to plan, initiate and monitor the speech gesture.

Given the findings from the majority of the aforementioned studies, there is valid evidence to support the existence of a discrepancy between IG and EG speech gestures. With this established, the question then becomes what speech characteristics define this discrepancy and what the implications are in terms of an underlying neuromotor mechanism responsible for its behavioral manifestation in

IG versus EG speech movements. To address this question, findings from Weir-Mayta (2014) will be further explored to better understand the underpinnings of motor speech impairments associated with PD. The goal of the study is to evaluate the vocal parameters of utterances produced by participants with PD in two contexts: covert conversation (an IG condition) and sentence reading (an EG condition). Given the associations between increased fluency, slower speaking rate and greater F0 variation, with increased intelligibility of EG speaking tasks revealed by Kempler and Van Lancker (2002) and Bunton and Keintz (2008), analysis will center on these measures. Loudness and mean word duration will not be analyzed as findings from Kempler and Van Lancker (2002) revealed these parameters did not account for differences in intelligibility across conditions. Additionally, vocal parameters will be considered in light of the severity of the speakers with PD (Kempler & Van Lancker, 2002; Sidtis et al., 2012) as well as the magnitude of the perceptual change noted between IG and EG conditions in the original study.

Specifically, the study is designed to answer the following research questions:

1. For the 10 speakers with Parkinson's disease from Weir-Mayta (2014), is there a significant difference between the IG speaking task (covert conversation) and the EG speaking task (reading aloud) for the vocal parameters of:
    a. Fluency (% dysfluent utterances across speaking conditions)
    b. Speaking rate (syllables per second)

c. F0 variability and range (average with standard deviation and range)

2. Are there within-group differences for the above vocal parameters in terms of:

    a. Speaker severity

    b. The magnitude of change between the IG and EG speaking task for the perceptual ratings of *naturalness* and *understandability*?

It is predicted that the externally cued speaking task of sentence reading will result in greater F0 variability and range, fewer dysfluencies and slower speaking rate than the internally cued task of covert conversation. It is also predicted that analysis of speech samples for participants with moderate to severe PD will reveal greater differences in measures of vocal parameters between IG and EG speaking conditions. Additionally, it is predicted that vocal parameters for speech samples for participants that did not demonstrate a perceptual change will reveal evidence of change between IG and EG speaking conditions. This is due to the fact that acoustic measures may be sensitive to changes that cannot be readily perceived by a listener.

Methods

Participants

According to Weir-Mayta (2014), participants were consented before study participation in accordance with the Institutional Review Board of the University of

Washington. Both speakers and listeners were paid for their participation. A total of 10 speakers with PD completed the study and consisted of nine males and one female ranging in age from 59-78 (M = 69.7, SD = 5.5). See Table 1 for an abridged summary of characteristics of PD participants. All participants were native speakers of American English, had adequate visual and hearing acuity, typical speech, language and cognitive developmental history and PD diagnosis by neurologist per self-report. All were required to pass a depression and cognitive screening and were at least 5 years post diagnosis (M = 10.6 years, SD = 6.2). Participants took prescribed medications throughout the study and were scheduled during optimal medication periods. Individuals who had undergone prior neurosurgical procedures including Deep Brain Stimulation (DBS) were excluded. Severity of hypokinetic dysarthria for PD participants varied from mild to severe and was verified by two expert listeners who are speech-language pathologists (SLP) and researchers with more than twenty years' experience working with individuals with PD. Expert listeners reviewed connected speech samples of each participant with PD and assigned perceptual ratings of previously defined *understandability* and *naturalness* using a four-point scale (i.e., normal, mild, moderate, severe). Expert listeners reached 100% agreement on all ratings.

Table 1: Characteristics of participants with Parkinson's Disease (PD).

Participant	Gender	Age	Years of Education	Etiology	Dysarthria Type	Severity Level- U	Severity Level- N	Years Since Diagnosis
PD1	M	74	20	PD	Hypokinetic	MOD	MOD	18
PD2	M	65	16	PD	Hypokinetic	MILD	MILD	8
PD3	M	72	16	PD	Hypokinetic	MOD	MILD	8
PD4	F	59	16	PD	Hypokinetic (+ spastic?)	MILD	MILD	20
PD5	M	73	16	PD	Hypokinetic	MOD	MOD	10
PD6	M	71	19	PD	Hypokinetic	SEV	SEV	10
PD7	M	64	18	PD	Hypokinetic	SEV	SEV	5
PD8	M	70	18	PD	Hypokinetic	MILD	MOD	5
PD9	M	78	18	PD	Hypokinetic	MILD	MILD	7
PD10	M	73	18	PD	Hypokinetic	MOD	MILD	5
Mean	*9 M,1 F*	*69.7*	*17.5*					*9.6*
SD		*5.5*	*1.4*					*5.3*

Note. U = Understandability; N = Naturalness; MOD = Moderate; SEV = Severe

Data Collection

Speech samples were collected using an AKG C520 head mounted microphone connected via MAudio hardware to the USB port of a computer running a custom MATLAB speech recording program. Mouth-to-microphone distance was kept constant at 2 inches. All files were automatically formatted and saved as 16 bit, 44,000 Hz wave files. The recording protocols for IG and EG speaking conditions of the original study are described here. To elicit IG speech sample (covert conversation), the examiner engaged the participant in conversation by asking open-ended questions (e.g., "What is the book you're reading?"), while setting up lab equipment. Speech produced by the participant was recorded without their knowledge. Once an adequate amount of speech was captured, the examiner revealed the presence and purpose of the recorded sample. After obtaining informed consent from the participant to use the sample, it was reviewed by the examiner who extracted the first five sentences of 5-15 words in length that met pre-specified criteria. These sentences were then used to elicit the EG speech sample (sentence reading). Sentences were typed into a Microsoft Word document using 20 pt. Arial font, double-spaced. When the participant was ready, the sentences were read directly off the computer screen while being recorded when provided the following instruction: "read each sentence aloud using your typical speech."

Data Analysis

Sentences from participants' covert-conversation files were clipped and processed in sound editing software (Adobe Audition 9.0). Following reading of the extracted sentences, each participant had a final 10 sentences (5 covert-conversation + the same 5 sentences read). The total number of listening samples generated for the PD group was: 10 speakers x 10 sentences [5 reading + 5 covert] = 100 stimulus items.

All acoustic data for the present study were analyzed on a MacBook Pro using Praat software (Boersma, 2011). The vocal parameter of speaking rate was operationally defined as the number of perceptually fluent syllables in each utterance divided by the duration (seconds) of the utterance, removing all instances of stuttering-like disfluencies, other disfluencies, and pauses greater than 250 milliseconds (ms) (syllables per second) (Chon, Sawyer & Ambrose, 2007). This definition was selected in order to capture the efficiency of participants' speech and, in particular, their ability to transition between articulatory postures of speech sounds. To calculate speaking rate for the spoken sentence of a given participant, all utterances were first transcribed. All disfluencies were removed and the number of perceptually fluent syllables spoken was counted. Pauses greater than 250 ms were removed from the total duration that was measured in Praat. The number of perceptually fluent syllables spoken was divided by the duration of the utterance measured in seconds, yielding a speaking rate measured in syllables per second.

Analysis of F0, the acoustic correlate of pitch, was performed to generate average F0, F0 standard deviation (F0SD), and F0 range for each sentence (Bunton & Keintz, 2008; Bowen, Hands, Pradhan, & Stepp, 2014). Each F0 contour for a given sentence underwent review by the author to eliminate misleading F0 values, i.e., single instances of F0 deviation whose values fall outside of the F0 range typically used by a speaker, as they would corrupt average F0 and F0SD by being too high or too low. This was done by decreasing the frequency range to eliminate spurious values. Then, the beginning and end of each utterance was highlighted and the average F0 and F0SD were recorded for the sentence. F0 range was calculated by determining the difference between the maximum and minimum F0. F0SD was calculated using the corresponding functions in Praat.

Analysis of the vocal parameter of fluency focused on within-word dysfluencies (e.g., sound and syllable repetitions). Justification for this focus arises from findings of Goberman, Blomgren, and Metzger (2008) that revealed a high quantity of within-word dysfluencies and a low quantity of between-word disfluencies (i.e., multi-syllabic repetitions, revisions and interjections) characterizing Parkinsonian speech. Within-word dysfluencies indicate motorically based dysfluency as opposed to between-word disfluencies that represent linguistically based and more typical dysfluency (Goberman et al., 2008; Guitar, 2014). Given this, analysis centered on those dysfluency types that best represent the motor speech deficits accompanying PD.

To evaluate the vocal parameter of fluency, the author calculated the percent dysfluent syllables per utterance for each speaker. Following orthographic transcription, each sentence was analyzed to determine the presence and number of dysfluent syllables. Dysfluent syllables were operationally defined as within word dysfluencies including: part word repetitions (sound and syllable repetitions), sound prolongations (inaudible and audible sound prolongations), mono-syllabic whole word repetitions, and broken words (i.e., words with an abnormally long and/or inappropriately placed mid-word pause (Goberman et al., 2008; Kempler & Van Lancker, 2002). The number of dysfluent syllables was then divided by the number of syllables in the utterance, yielding a percentage of dysfluent syllables per utterance in IG and EG speaking tasks. See Table 2 for comparisons of IG versus EG tasks for each participant, planned statistical analyses, and predictions for these comparisons. See Table 3 for additional within group comparisons.

Table 2. Comparisons of internally guided (conversation) versus externally guided (reading) tasks for 10 speakers with Parkinson's disease.

IG-conversation	EG- reading	Analysis	Predictions
% dysfluent syllables	% dysfluent syllables	Paired t-tests	Reduced dysfluencies in EG task
speaking rate	speaking rate	"	Slower rate in EG task
F0 mean F0SD F0 range	F0 mean F0SD F0 range	"	Greater pitch variability in EG task

Table 3. Additional within group comparisons based on severity and perceived changes to *naturalness*/*understandability*.

IG-EG (difference) for dysfluencies, rate, pitch		Analysis	Predictions
Mild PD	Mod-sev PD	Mann-Whitney Test	Participants with moderate-severe PD will have greater differences in the vocal parameters between IG and EG speaking conditions.
No perceptual change to *naturalness*	Perceptual change to *naturalness*	Pearson correlation	Participants who were perceived to have improved *naturalness* will show the greatest change in variables related to pitch.
No perceptual change to *understandability*	Perceptual change to *understandability*	Pearson correlation	Participants who were perceived to have improved *understandability* will show the greatest change in variables related to speech rate and dysfluencies.

Results

Reliability

For all aforementioned analyses, intra-rater reliability was determined by having the author re-evaluate 10% of the utterances. To assess inter-rater reliability, a second trained researcher analyzed 10% of the utterances. Utterances were randomly selected using the random number generator function in Excel. Pearson correlations were used as the metric of reliability. Intra-rater reliability yielded correlations ranging from .968-1.0 for all variables and were all significant at $p < 0.001$. Inter-rater reliability yielded correlations ranging from .912 for rate of speech to 1.0 for minimum pitch. The correlations of all variables were significant at $p < 0.001$. In sum, a high degree of reliability was demonstrated across raters for all variables.

IG vs. EG Speaking Tasks

Paired t-tests were used to determine the presence of a difference in performance between the IG and EG speaking conditions for each speaker and vocal parameter. An alpha level of .05 was established.

<u>Speaking Rate and Fluency</u>

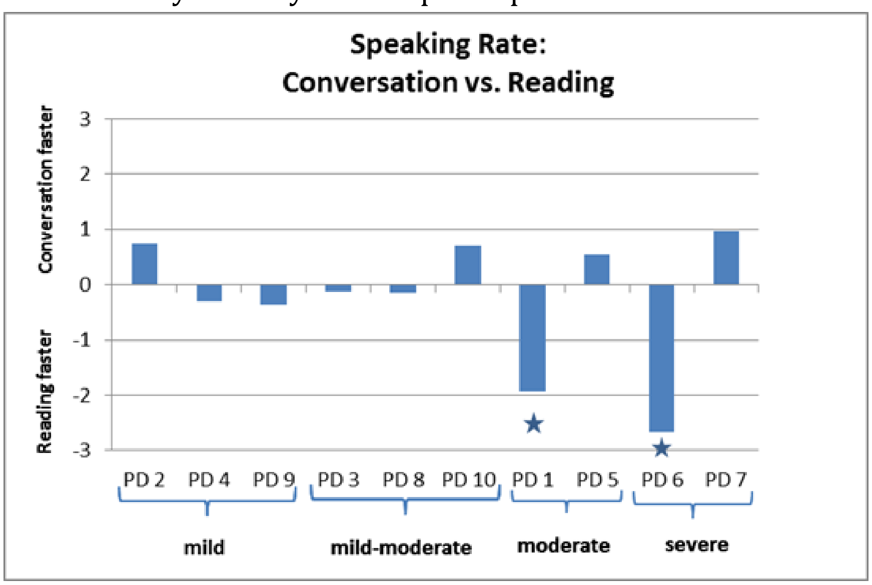
Differences between average speaking rates measured from IG to EG speaking conditions for each participant are shown in Table 4 and Figure 1. Four participants demonstrated decreases in speaking rate in the reading task, though none of these decreases were statistically significant. Six participants increased

Table 4. Differences in average speaking rate and % dysfluency between IG and EG speaking conditions and corresponding p values by participant.

	Speaking Rate (syllables/second)				% Dysfluency			
	Conversation	**Reading**	**Diff**	***p* value**	**Conversation**	**Reading**	**Diff**	***p* value**
PD1	3.74	5.68	-1.94	0.028*	12.43	0	12.43	0.018*
PD2	5.12	4.37	0.75	0.117	0	0	0	n/a
PD3	3.58	3.7	-0.12	0.622	0	0	0	n/a
PD4	3.34	3.65	-0.31	0.386	0	1.54	-1.54	0.374
PD5	4.76	4.22	0.54	0.375	0	0	0	n/a
PD6	2.43	5.1	-2.67	0.004*	15.48	0	15.48	0.049*
PD7	5.31	4.34	0.97	0.136	0	0	0	n/a
PD8	6.93	7.08	-0.15	0.746	2.23	0	2.23	0.178
PD9	4.32	4.68	-0.36	0.525	1.82	0	1.82	0.374
PD10	6.25	5.54	0.71	0.467	0	2.22	-2.22	0.374

**p < 0.05. Diff = difference score reflecting conversation parameter – reading parameter.*

Figure 1. Differences in average speaking rate between IG and EG speaking conditions by severity-ranked participants.

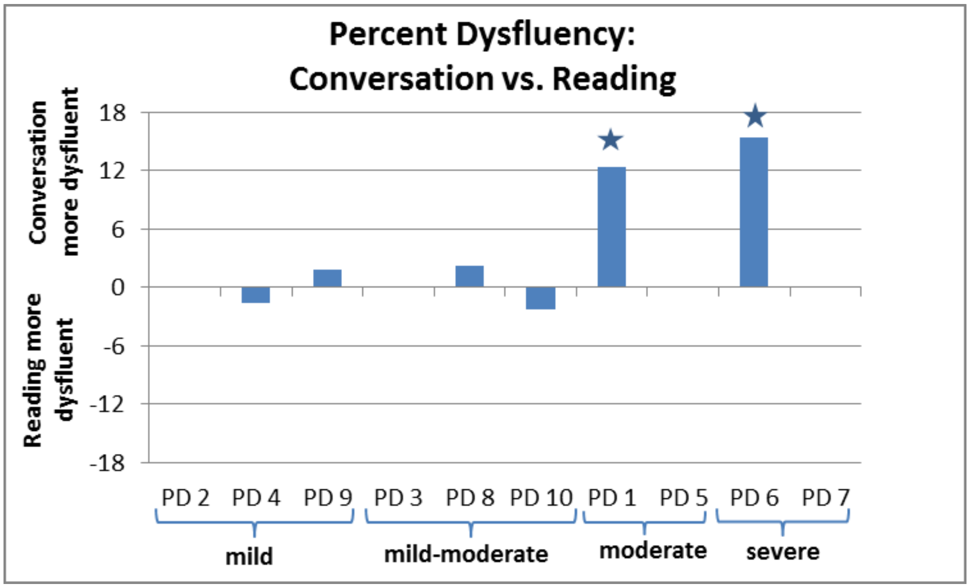


★ *p < 0.05*

their rate of speech in the reading task. Participants PD1 and PD6, in particular, had a significantly faster speaking rate (p=.028 and .004, respectively) from the internally guided conversation to the externally guided reading condition (M=1.94 syll/sec, SD=1.28 and M=3.16 syll/sec, SD=.03). Findings for PD6 should be interpreted with caution, as only two of five utterances produced in the IG speaking task were intelligible to the author and therefore able to be included in the analysis.

Differences between average percent dysfluent syllables for utterances produced in the IG speaking condition (i.e., covert conversation) to EG speaking condition (i.e., reading) for each participant are shown in Table 4 and Figure 2. Participants PD1 and PD6 demonstrated significant decreases (p=.018 and .049, respectively) in percent dysfluent syllables from the IG to EG speaking conditions (M=12.43, SD=7.16 and M=15.48, SD=1.68). The caution mentioned above for PD6 applies here as well. Participants PD8 and PD9 also demonstrated decreases in this measure between IG and EG speaking conditions, though these differences were not significant. Regarding other participants, two demonstrated slight increases in dysfluency in the externally guided reading task while four demonstrated no motoric-based dysfluencies in either speaking condition.

Figure 2. Differences in average % dysfluency between IG and EG speaking conditions by severity-ranked participants.



★ $p < 0.05$

Fundamental Frequency Measures

Differences between average F0, F0SD, and F0 range from IG to EG speaking conditions for each participant are shown in Table 5 and Figures 3-5. Statistically significant increases in average F0 measures from the conversation to the reading task were observed for the following three participants: PD1 (M=10.29Hz, SD=4.48; p=.007), PD7 (M=16.20Hz, SD=4.97; p=.002) and PD9 (M=14.01Hz, SD=5.13; p=.004). Participant PD2 demonstrated a statistically significant decrease in average F0 from conversation to reading (M=-8.43, SD=6.71; p=.048). Three additional participants demonstrated an increase in average F0 and another three a decrease in average F0, although these differences were not significant. For F0 standard deviation, which reflects pitch variability, PD6 was the sole participant to demonstrate a significant difference in F0SD (p=.007). Namely, analysis revealed an increase in F0SD from IG to EG speaking (M=4.34, SD=1.88). An additional six participants also demonstrated increases in F0SD from IG to EG speaking conditions, though these increases were not significant. The remaining three participants had decreased F0 variability in the reading task, though these differences also did not reach significance. Analysis of F0 range revealed no significant differences from IG to EG speaking conditions.

Within Group Differences by Speaker Severity

Analyses of within group differences by speaker severity were restricted based on missing data (e.g., unintelligible utterances for calculation of speaking rate and dysfluencies), as well as unequal group numbers. The nonparametric Mann-Whitney U test was used to compare the fundamental frequency parameters of speakers ranked mild/mild-moderate to those ranked moderate/severe in the original study (Weir-Mayta, 2014). Difference scores were used in the analyses. No group differences by severity were found for mean F0 ($U = 9.0$, $p = .522$), F0SD ($U = 8.0$, $p = .394$) or F0 Range ($U = 5.0$, $p = .136$). Speaking rate and % dysfluencies were not analyzed because of missing data from unintelligible utterances.

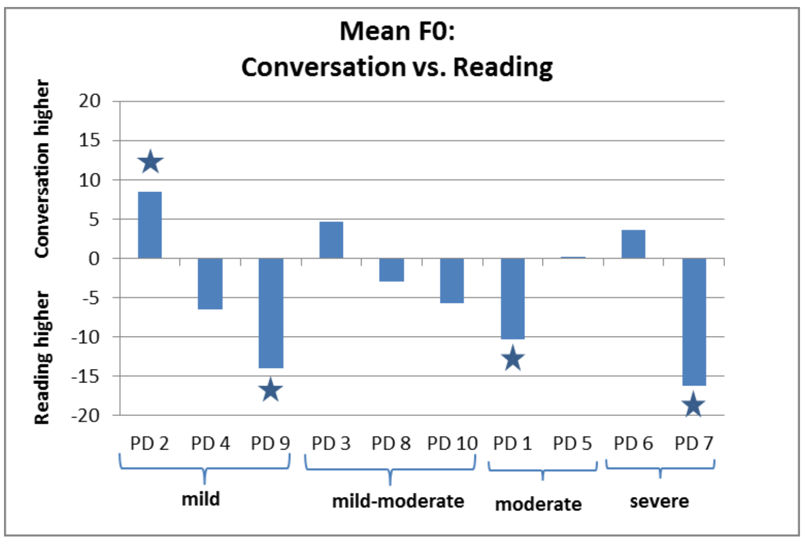
Visual inspection of the data in Figures 1-5 suggests that the two speakers with significant changes to speaking rate and fluency from the conversation to the reading task were both on more severe end of the severity continuum.

Table 5. Differences in fundamental frequency parameters from IG to EG speaking conditions and corresponding *p* values.

	Mean F0				**F0 Standard Deviation**				**F0 Range**			
	Conversation	Reading	Diff	*p* value	Conversation	Reading	Diff	*p* value	Conversation	Reading	Diff	*p* value
PD1	127.64	137.93	-10.29	0.007*	16.32	15.68	0.64	0.777	98.55	88.58	9.97	0.445
PD2	151.09	142.66	8.43	0.048*	27.39	17.84	9.55	0.136	167.21	120.39	46.82	0.208
PD3	123.78	119.07	4.71	0.076	19.47	22.92	-3.45	0.433	135.49	128.3	7.19	0.806
PD4	117.87	124.37	-6.5	0.297	15.91	22.12	-6.21	0.190	99.09	96.69	2.4	0.081
PD5	156.26	156.08	0.18	0.973	20.14	23.05	-2.91	0.304	122.94	160.15	-37.21	0.093
PD6	135.11	131.49	3.62	0.376	7.02	11.36	-4.34	0.007*	49.23	58.62	-9.39	0.407
PD7	98.99	115.19	-16.2	0.002*	10.42	14.86	-4.44	0.188	73.65	90.44	-16.79	0.524
PD8	111.77	114.71	-2.94	0.566	19.24	14.99	4.25	0.293	87.62	71.62	16	0.130
PD9	102.73	116.74	-14.01	0.004*	16.54	16.63	-0.09	0.973	88.82	94.22	-5.4	0.734
PD10	132.3	138.05	-5.75	0.241	13.02	14.8	-1.78	0.237	74.32	87.85	-13.53	0.178

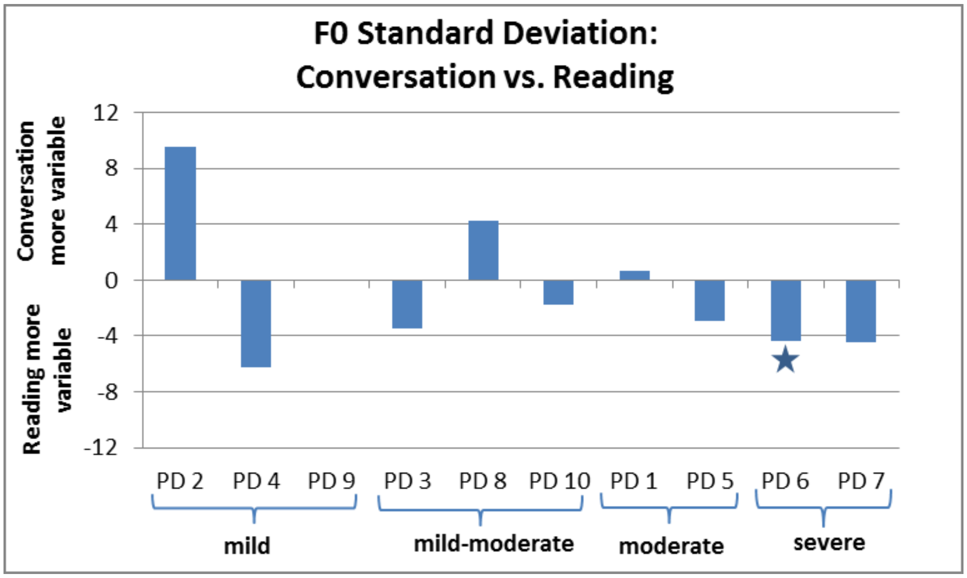
* $p < 0.05$

Figure 3. Differences in average F0 from IG to EG speaking conditions by severity-ranked participants.



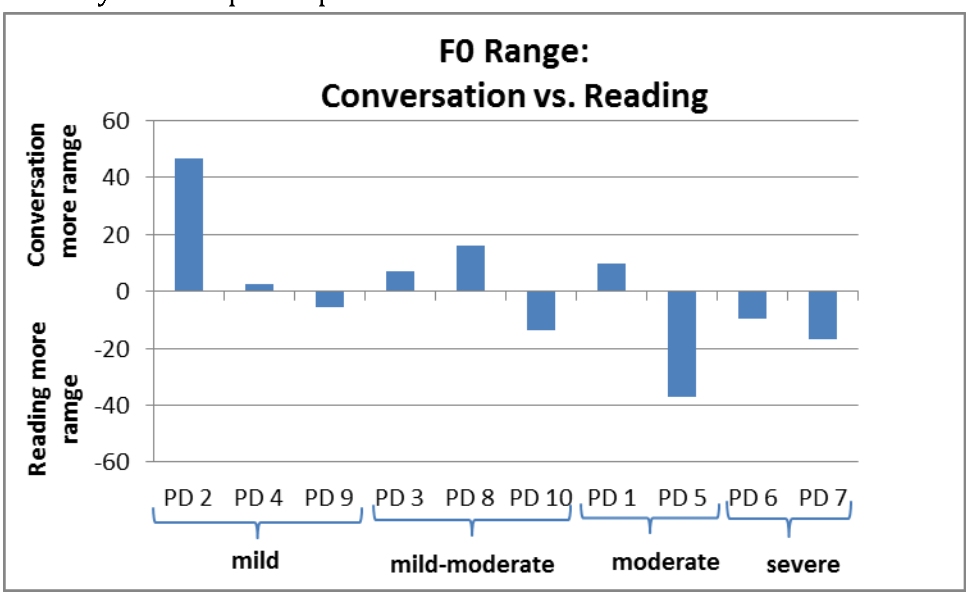
★ *$p < 0.05$*

Figure 4. Differences in average F0SD from IG to EG speaking conditions by severity-ranked participants.



★ *$p < 0.05$*

Figure 5. Differences in average F0 Range between IG and EG speaking conditions by severity-ranked participants.



★ *$p < 0.05$*

Within Group Differences: Changes in vocal parameters as they relate to Understandability and Naturalness

In the original Weir-Mayta (2014) study, expert listeners perceptually rated the ten speakers with PD with respect to *understandability* and *naturalness*. Those speakers who had a marked change to *understandability* or *naturalness* from the covert conversation condition to the reading condition are the focus of the remaining analyses.

A meaningful difference in perceptual measures of *understandability* and *naturalness* from IG to EG speaking conditions was operationally defined as a 10 mm or greater difference on the 100-point visual analogue scale used by Weir-Mayta (2014). Six participants were identified as exhibiting a meaningful difference for the perceptual parameter of *understandability* and five for the perceptual parameter of *naturalness*. Table 6 delineates the magnitude of these differences by participant with the corresponding statistically significant differences in vocal parameters described in the preceding section.

As evidenced by the above table, for four of the six participants with meaningful differences in perceptual measures, the vocal parameters in the current study did not capture aspects of the speech signal that related to improved perceptual measures in the EG speaking condition. However, two of the six participants in this group demonstrated a similar pattern of a significant decrease in percent dysfluent syllables and a significant increase in speaking rate.

Table 6. Meaningful differences in perceptual measures of *understandability* and *naturalness* and corresponding statistically significant changes in vocal parameters analyzed by participant.

	Participant	Meaningful perceptual difference for *understandability*	Meaningful perceptual difference for *naturalness*	Significant differences from conversation to reading task[1]
Perceptual change from conversation to reading in Weir-Mayta (2014)	PD1	23.9	28.2	- % dysfluent syllables + speaking rate + average F0
	PD3	21.1	14.5	None
	PD6	14.9	N/A	- % dysfluent syllables + speaking rate + F0SD
	PD7	53.4	35.7	+ average F0
	PD8	13.4	10.9	None
	PD10	18.4	15.1	None
No perceptual change from conversation to reading in Weir-Mayta (2014)	PD2	N/A	N/A	- average F0
	PD4	N/A	N/A	None
	PD5	N/A	N/A	None
	PD9	N/A	N/A	+ average F0

[1]+ signifies an increase in variable indicated; - signifies a decrease in variable indicated

Pearson correlations were used to compare EG to IG differences in vocal parameters from the current study, and EG to IG differences in perceptual ratings of *understandability* and *naturalness* from the original study (Weir-Mayta, 2014). The results revealed a significant negative correlation between percent dysfluent syllables and ratings of *naturalness* (r= -0.29; p=.05), and a significant positive correlation between average F0 measures and ratings of *understandability* (r= 0.364; p=.009) and *naturalness* (r= 0.443; p=.001). While significant, the strength of the correlations can be considered weak to moderate. No other correlations between the difference scores of speech parameters and perceptual parameters were significant.

Also, participants PD2 and PD9 demonstrated a statistically significant increase and decrease in average F0, respectively, but did not demonstrate meaningful differences in perceptual parameters of *understandability* and *naturalness*.

Discussion

The goal of the present study was to evaluate the vocal parameters of fluency, speaking rate and F0 for utterances produced by participants with PD in two contexts: covert conversation (an IG condition) and sentence reading (an EG condition). Vocal parameters were considered in light of the severity of the speakers with PD (Kempler & Van Lancker, 2002; Sidtis et al., 2012) as well as the magnitude of the perceptual change noted between IG and EG conditions in the original study by Weir-Mayta (2014).

It was predicted that the externally cued speaking task of sentence reading would result in greater F0 variability and range, fewer dysfluencies and slower speaking rate than the internally cued task of covert conversation. It was also predicted that speech samples for participants with moderate to severe PD would reveal greater differences in measures of vocal parameters between IG and EG speaking conditions. Additionally, it was predicted that vocal parameters for speech samples for participants that did not demonstrate a perceptual change would reveal evidence of change between IG and EG speaking conditions, due to the fact that acoustic measures may be sensitive to changes that cannot be readily perceived by a listener.

IG (conversation) versus EG (reading) comparisons

Findings from this study reveal statistically significant differences between speaking conditions for a small number of participants that mostly center on participants PD1 and PD6. Specifically, these speakers both demonstrated significant decreases in percent dysfluent syllables and significant increases in speaking rate in the EG condition compared to the IG condition. Additionally, PD1 exhibited a significant increase in average F0 and PD6 a significant increase in pitch variability (F0SD) in the externally-guided reading task. Two additional participants exhibited a significant increase in average F0 and one a significant decrease in average F0. Lastly, no significant differences were observed for the vocal parameter of F0 range.

These findings reveal few discernable group trends between IG and EG speaking tasks. However, of the two participants with marked dysfluencies in the conversation condition, both speakers became completely fluent in the reading condition. Specifically, PD 1 shifted from 12.4% syllables stuttered in the conversation condition to 0% syllables stuttered in the reading condition. Similarly, PD 6 shifted from 15.5% syllables stuttered in the conversation condition to 0% syllables stuttered in the reading condition. This finding aligns with the prediction of reduced dysfluencies in the EG task. Reading is a well-known fluency enhancing condition for individuals with developmental dysfluencies (Young, 1980) and served to improve the fluency of speakers with basal ganglia disruption from PD as well. Findings from studies performed with individuals with PD have also documented enhanced fluency in reading conditions, which has been attributed to the provision of external cues (Kempler & Van Lancker; Goberman et al., 2008). As previously discussed, authors of these studies hypothesize that basal ganglia dysfunction due to decreased dopamine levels in the brain results in the absence of the internal cues necessary to guide volitional movements, e.g., conversational speech. Therefore, provision of an external model, e.g., reading, bypasses the need for these internal cues and provides aid to the basal ganglia with which to plan, initiate and monitor the speech gesture. Additionally, Goberman et al. (2003) postulated that the dysfluencies observed in individuals with PD may be related to increases *or* decreases in dopamine levels after their study revealed both increases and decreases in dysfluency for participants with PD between *on* and *off* states of levodopa medication (but no discernable group trend). Both of these hypotheses align with conclusions drawn by Alm (2004) that implicate the same neuromotor circuitry that originates from the basal ganglia and extends to the SMA and its deregulated dopamine levels (i.e., either increased or decreased) as the underlying pathophysiology of developmental stuttering. Thus, PD and developmental stuttering may share critical aspects of pathophysiology that explain similarities in findings across studies, though further research is needed to validate these hypotheses.

Contrary to our prediction of slower speaking rates in the EG reading task, the majority of group members exhibited increases in speaking rate from the IG task to the EG task. However, only two of these differences reached significance (PD1 and PD6). The original hypothesis of slower speaking rate in the EG task was motivated by the premise that speakers would be more intelligible in the reading task and this intelligibility would be mediated by a slower speaking rate (Bunton & Keintz, 2008). However, this hypothesis assumes that dysfluencies are not the predominant characteristic of a speaker's hypokinetic dysarthria; if they were, one would hypothetically see an increase in speaking rate. To illustrate with findings from the current study, the same two participants who demonstrated greater dysfluencies and slower speaking rates in the IG task (covert conversation) also exhibited significantly fewer dysfluencies and a faster speaking rate in the EG task (reading aloud). These findings highlight a relationship between frequency of speech dysfluencies and speaking rate, and allude to those found in the child fluency literature which suggests that children who produce more dysfluencies in their speech also exhibit slower speaking rates (Tumanova, Zebrowski, Throneburg & Zayikci, 2011). The findings also serve as a reminder for the careful consideration of distinctions between speaking rates that include dysfluencies (i.e., "speech rate") and those that do not (i.e., "articulation rate"), and thus capture different aspects of speech production.

Overall, predictions made regarding frequency measures were not supported by the findings. Statistically significant increases in average F0 were observed for nearly half of the speakers, but the utility of this measure is questionable when one considers the possible influence of task on the speech behavior observed. Namely, there exits the possibility that a person, whether neurotypical or not, will exhibit a higher F0 when reading aloud than when speaking extemporaneously (Hollien, Hollien & Jong, 1997; Abu-Al-makarem & Petrosino, 2007), though further research is needed to confirm this pattern. This raises concerns regarding the interpretability of the increases observed for average F0 between speaking conditions as the increased pitch may be due to the nature of the task and not to the external cues provided during the reading condition.

While increased pitch variability was indeed observed for one participant (PD6) in the externally-guided reading task, the remaining participants did not show statistically significant change between conditions and varied in the direction of that change. Similarly, statistically significant increases in F0 range were not observed and may reflect a measure that is not sensitive to the frequency variability this study sought to capture. According to Bowen, Hands, Pradhan, & Stepp (2014), measures of F0 range are, "highly corruptible by single time-points and thus are less appropriate estimations of overall prosodic variation" (pp. 236). Instead, as evident in Colton, Casper and Leonard (2006), F0SD is the measure that more appropriately reflects frequency variability provided the speech sample is sufficiently long. In this study, six of the ten participants demonstrated greater F0 variability in the EG speaking condition though, as stated above, only one participant demonstrated a significant increase in F0SD from IG to EG speaking conditions. These findings contrast with those of the original study (Weir-Mayta, 2014) where five of the ten speakers with PD had a pronounced improvement to *naturalness* in the reading condition. Thus, the question arises of why more significant increases in F0SD were not observed in this study? One possibility may be inadequate speech sample size;

five utterances that are each generally five seconds or less in length may not be sufficiently long enough to allow for adequate representation of a given speakers frequency variability. Another possibility is that the findings were influenced by the male-dominated sample (9/10 speakers) as male speakers, including those with PD, have less overall F0 variability than female speakers (Bowen et al., 2014).

Speaker Severity

The present findings lend some support to the prediction that participants with moderate to severe PD would reveal greater differences in measures of vocal parameters between IG and EG speaking conditions. Namely, the two participants who showed statistically significant changes were both on the more severe end of the severity continuum. PD1 was rated by expert listeners as moderately impaired for both *understandability* and *naturalness*, while PD6 was rated as severe for both *understandability* and *naturalness* (Weir-Mayta, 2014). However, no overt group differences emerged for all speakers of a given severity. Rather, changes exhibited by participants in measures between speaking conditions were markedly heterogeneous, thus compromising the interpretability of any potential statistical analysis of participants as an aggregate.

Comparison to previous IG versus EG studies of speech in PD

Findings from this study are in partial agreement with Kempler & Van Lancker (2002) who evaluated a speaker with PD and moderate hypokinetic dysarthria across five speaking tasks. While the focus of their study was intelligibility, the authors reported significantly greater dysfluencies in spontaneous speech versus the other speaking conditions (reading, repeating, etc.) which aligns with the pattern of the two dysfluent speakers in the present study (PD1 and PD6). That is, the two speakers who showed substantial dysfluencies in the IG speaking condition (conversation) were both significantly less dysfluent in the EG speaking condition (reading). However, marked variability was observed overall in the speech dysfluencies of the participants in the current study, with four speakers exhibiting no dysfluencies in either condition.

A similar pattern of fewer dysfluencies in an externally cued task (repetition) versus monologue was reported by Sidtis et al. (2012). As a whole, Sidtis and colleagues suggested that the magnitude of the differences between IG and EG conditions, for measures of intelligibility and listener difficulty, may have been greater if their speaker sample was more compromised. Their group of 11 speakers with PD all had mild hypokinetic dysarthria. While group analyses in the present study did not find strong patterns related to severity, it should be reiterated that the two participants who demonstrated the majority of significant changes in measures between IG and EG speaking condition were indeed at the more severe end of the spectrum for their hypokinetic dysarthria (i.e., PD1 moderate, PD6 severe).

Group findings from the current study support those of Tjaden & Wilding (2011) and Bunton & Keintz (2008) that revealed negligible benefit from provision of external cues in speaking tasks. However, unlike findings from Bunton & Keintz (2008) that revealed an association of greater intelligibility with slower speech rate and greater F0 variability, in this study the majority of utterances perceived as significantly more understandable and natural (Weir-Mayta, 2014) were produced with both a faster speech rate and with comparable F0 variability between IG and EG speaking conditions. Though, as previously stated F0 variability measures in this study (i.e., F0SD) may have been compromised by insufficient length of speech samples and/or this study's male dominated sample.

Some findings from this study are congruent with those of Weir-Mayta (2014) that revealed speakers with PD were significantly more *understandable* and *natural* in the EG speaking condition. Specifically, of the six speakers in the original study who exhibited a meaningful difference in perceptual measures from IG to EG speaking conditions, two demonstrated a similar pattern of change in acoustic measures (i.e., PD1 and PD6 who were less dysfluent and had a faster speaking rate in the EG speaking condition). For the remaining four speakers, it is hypothesized that the vocal parameters selected for analysis may not have been adequately sensitive to the changes this study sought to capture in Parkinsonian speech between IG and EG speaking conditions. For example, participant PD10 exhibited meaningful differences in perceptual measures of both *understandability* and *naturalness*, yet no significant quantitative differences in measures analyzed in this study. Is there another aspect of the speech signal that this study overlooked that could quantitatively capture what expert listeners perceived in Weir-Mayta (2014)? To illustrate, participant PD3 exhibited slurred speech in the IG speaking condition that noticeably improved in the EG condition, as judged by the author. Additionally, participant PD7 exhibited marked change to perceptual ratings for *understandability* and *naturalness* from IG to EG speaking conditions in Weir-Mayta (2014), but no significant change to speech parameters other than a higher average fundamental frequency during the reading task. Perhaps some other acoustic measures known to be sensitive to the speech characteristics of Parkinsonian speech (e.g., F0 variability measures generated with sufficiently long speech samples, jitter and shimmer measures, signal-to-noise ratio; Colton, Casper & Leonard, 2006) could better capture these changes.

An additional consideration is that presentation of hypokinetic dysarthria is so varied it invalidates researching participants with PD as an aggregate. To illustrate, analysis of the vocal parameter of fluency in this study revealed significant decreases in dysfluency for two participants, subtle decreases *and* increases for four participants, and no motoric dysfluencies in either speaking condition for four participants. Additionally, slower speech rates for four individuals in Bunton & Keintz (2008) were associated with greater intelligibility whereas faster speech rates for ten participants were associated with greater *understandability* and *naturalness* in Weir-Mayta (2014). Thus, the validity of using an aggregate model to perform research with individuals with PD is challenged (Fischer & Goberman, 2010). Perhaps a more effective research model for individuals with PD would be to consider them individually and/or investigate the existence of PD subgroups, whereby individuals with PD would be organized into meaningful groups based on measures that capture the dominant yet distinguishable characteristics of hypokinetic dysarthria (e.g., percent dysfluent syllables as it relates to fluency, speech rate as it relates to intelligibility, etc.). Subgroups are emerging with respect to motor (e.g., tremor, bradykinetic-rigid) and non-motor (e.g., cognition, mood) symptoms of PD (Berganzo, Tijero, Gonzalez-Eizaguirre, Somme, Lezcano, et al., 2014; Katzen, Levin, & Weiner, 2006), which has helped to bring clarity to the characterization of this diverse group. Consideration of research findings in such contexts allows for greater distinction of an individual's unique presentation of hypokinetic dysarthria characteristics and may lend itself to better interpretation of said findings and thus, greater insight into hypokinetic dysarthria associated with PD.

Future Research

Further research exploring presentation of hypokinetic dysarthria is warranted due to the notable lack of clarity pertaining to characteristics of Parkinsonian speech in IG and EG task paradigms in this study and the extant literature. Efforts should identify vocal parameters that are sensitive enough to adequately capture perceptual changes in Parkinsonian speech, as these features may be the most powerful speech characteristics to target therapeutically. As stipulated in the American Speech-Language Hearing Association's (ASHA) position statement on evidence-based practice (ASHA, 2005), speech-language pathologists must, "evaluate the efficacy, effectiveness, and efficiency of clinical protocols for prevention, treatment, and enhancement using criteria recognized in the evidence-based practice literature" (bullet 4). This statement has multiple implications for appropriate evidence-based assessment and treatment of individuals with PD and hypokinetic dysarthria. At the forefront of implications for clinical practice is the necessity of understanding the possible effects of external cueing on speech performance and to consider its influence when interpreting clinical findings for measures elicited in EG task paradigms (e.g., reading aloud). Intelligibility testing is a common assessment performed with individuals with PD and hypokinetic dysarthria. Assessment measures used to perform intelligibility testing often combine speech tasks such as reading aloud or repetition which may not yield ecologically valid measures that capture the impact of hypokinetic dysarthria on the individual's activities of daily living (Kempler & Van Lancker, 2002; Tjaden & Wilding, 2011). Intelligibility scores are also used to make critical clinical decisions such as when it is appropriate to discharge a patient from services, further highlighting the need for ecologically valid measures (Bunton & Keintz, 2008) that account for changes in speech performance with the provision of external cues.

Increased speech performance via provision of external cues also yields clinical implications for treatment programs commonly used to treat hypokinetic dysarthria, namely, Lee Silverman Voice Treatment (LSVT). The focus of the LSVT program is to train loudness to achieve several speech goals, using a single self-cue (i.e., "Think loud!") to facilitate generalization of treatment effects to functional communication (Fox, Ramig & Sapir, 2012). LSVT treatment tasks increase in complexity over the course of therapy from words to phrases, sentences, reading and conversation to support generalization in use of this self-cue and improved speech. However, if individuals with PD consistently perform better on speaking tasks when provided external cues, it may be necessary for treatment programs to consider alterations to their existing programs such that external cues are consistently provided throughout the generalization process.

Thus, with the need for future research established, the question becomes prioritizing the focus of these future studies. Firstly, future research is needed to determine if individuals with PD demonstrate significant increases in speech performance with the provision of external cues, as there remain no conclusive findings to justify or invalidate this hypothesis. To that end, further research is needed to better understand the neural circuitry underlying IG versus EG motor movements as well as the mechanism by which provision of external cues compensates for basal ganglia dysfunction. This research should be conducted with paradigms that allow for distinction between changes resulting from provision of external cues and those that result from related factors (e.g., attention). If differences in performance based on provision of external cues are identified, research should also be conducted to examine how these differences manifest in and are influenced by assessment and treatment procedures. Of equal importance to explication of EG task effects on Parkinsonian speech is the need to explore the efficacy of researching individuals with PD individually or as an aggregate. Further, devoting future research to exploring the possibility of PD subgroups may be warranted if patterns emerge among persistent and seemingly heterogeneous findings among and between studies. Lastly, future research should be devoted to identification of vocal parameters whose measures best correlate with and/or represent the speech characteristics of hypokinetic dysarthric speech, as there is limited consensus on which parameters adequately capture characteristics of Parkinsonian speech (Colton, Casper & Leonard, 2006).

Limitations

This study had several limitations that compromised interpretation of its findings. Firstly, a small sample size (i.e., 10 participants) was used, which limits straightforward application of this study's findings to the larger population of individuals with PD. There was also no age-matched control group with which to determine typical differences in speech produced in IG and EG speaking conditions. Further limitations include lack of sensitive acoustic measures to capture changes perceived by expert listeners in the original study, acoustic samples that were possibly of insufficient length to adequately capture vocal parameters analyzed in the study (i.e., F0SD) and/or the male-dominated sample. Lastly, unintelligible utterances for two participants resulted in the author's inability to generate a complete data set of measures for percent dysfluent syllables and speaking rate, thereby limiting the analyses of these vocal parameters.

Conclusion

This study explored the differences in speech of individuals with PD between IG and EG speaking conditions by analyzing quantitative vocal parameters of fluency, speaking rate and fundamental frequency. Results revealed meaningful, significant differences for two of the ten speakers between speaking conditions. Namely, two speakers had significantly enhanced fluency and a faster rate of speech in the externally-cued reading condition. Findings only partially align with those of the original study that revealed significant group differences for the perceptual measures of *understandability* and *naturalness* between IG and EG speaking conditions for six of the ten speakers. Future research is needed to continue to explicate the effects of external cuing on motor speech performance in individuals with PD.

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